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Static and Dynamic Performance During Precision Fine Motor Tracking

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Static and Dynamic Performance During Precision Fine Motor Tracking

by

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Abstract

Static and Dynamic Performance During Precision Fine Motor Tracking

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Studies of static and dynamic motor control have a long research history. In most cases, studies have focused on one condition or the other. However, it is important to determine whether differences exist between the two types of task, especially when used in conjunction with task performance. Video game controllers, motorized wheel chairs, steering wheels, and robotic surgical equipment are all examples of how modern equipment uses static and dynamic motor control to achieve task performance goals. To this end, this study aimed to examine possible differences in accuracy or consistency of performance between static and dynamic variations of a precision fine motor tracking task. Nineteen healthy, right-handed volunteer participants were asked to manipulate a cursor to track a moving target with both index fingers, using a static control method in one task and a dynamic control method in another task. The cursor was to follow as closely as possible a target traveling along a diagonal line and back. The control methods were tested during two different testing sessions to reduce confounding of the task conditions. After 50 practice trials in a condition, 5 test trials were recorded. Two dependent variables, RMSE and CVE, were used to represent task performance as indicators of accuracy and consistency, respectively. Analyses of variance with a Latin Square design were used to compare overall performance of each dependent variable between the two conditions. Results showed a significant difference in both variables with p-values less than .001; tracking accuracy was better on the static task and cursor motion consistency was better on the dynamic task. These findings suggest that performance aspects of a fine motor control task does vary with control method and can be used to aid equipment design and task performance in the future.

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Chapter 1: Introduction

Interest in man's mobility and movement was documented in Aristotle's Physics as early as 384 B.C. (Hope, 1961). This interest in the evolution of human movement and mechanics has spurred fields from philosophy to biology to psychology to engineering to art and beyond. This single interest has the ability to bridge any number of obscure, unrelated disciplines and bring them together in a fully comprehensive picture of what makes humans unique.

Humanity's apparent exclusiveness to these motion patterns has led to the investigation of what makes man different and how the abilities to learn and move and survive have catapulted our species to the top of the food chain. The advancement of technology through time has enabled researchers to seek more in depth understanding of the mechanisms driving the human body. Through this investigative process, motor learning and control have expanded into major fields of study concerned with the processes of learning and performing motor skills across all levels of experience, from novel to expert (Schmidt, 2005).

Because the human body is so complex, skill acquisition and performance can be attributed to many different neurological and musculoskeletal mechanisms, both centrally and peripherally. Some number of combination of these mechanisms allow the human body to execute tasks as delicate as catching a snowflake without crushing it and as robust as moving hundreds of pounds of weight in a single instant. The differentiation of these tasks and the control required to complete such a wide range of abilities has led researchers to seek out the specific pathways and mechanisms driving this variety of possible motor tasks.

Typically, the musculoskeletal system is used to produce motion, maintain balance and posture, provide protection to vital organs, and create and harvest energy necessary for life (McGinnis, 2005). In order to create movement, muscles undergo various types of contractions that change joint angles and alter limb positions in coordinated and controlled patterns. These motor tasks can be defined using two different categories, static or dynamic. Concentric and eccentric contractions of muscles, in which a highly adapted process leads to shortening or lengthening muscles regulating movement of the limbs to which the muscles are attached, are dynamic in nature. Isometric muscle contractions, in which force is produced but muscle length and limb position do not change, are static (McGinnis, 2005). Most activities of daily living seamlessly incorporate both dynamic and static tasks in unlimited combinations. Walking, standing, sitting, talking, driving, eating, and writing are all examples of activities using a combination of both types of contractions to achieve a single task-oriented goal. The mechanisms that govern the control of these tasks vary and adapt to the requirements of the tasks themselves (Mugge et al., 2010).

Research has explored motor unit recruitment and firing rates, force-velocity relationships, kinesthetic and proprioceptive feedback under varying conditions, and many other physiological and behavioral aspects of muscle action in a wide array of ballistic tasks such as kicking, jumping, throwing, sit-to-stand, and striking (Edman, 1979; Milner-Brown et al., 1973; McGrain, 1980; Brush, 1966; Gordon et. al., 1984; Parmley et. al., 1970; Murphy et. al., 1995). Throughout this range of research, isometric force control (static movement) and free motion (dynamic movement) have been consistently separated. This separation has been necessary to determine the different pathways and feedback systems that respond to all-force-no-motion tasks versus all-motion-low(or no)-force tasks. Different sensory receptors are dominant during these conditions and influence motor control processes at different levels of the central and peripheral nervous systems (Haines, 2002).

Because scientific research is transitioning to a focus on clinical relevance, this is a field that has great promise in continuing to move forward by the comparison and integration of these motor tasks previously studied separately. Populations with movement and neurological disorders as well as traumatic brain injury can benefit from rehabilitation techniques and improved equipment that utilize the most efficient and stable activities with carefully delineated motor control mechanisms and analysis.

1.1 STATIC MOTOR CONTROL

Any motor task that only involves isometric contraction is defined as a static motor skill. Using this definition, static motor control is primarily the control of force production in a muscle or group of muscles working isometrically at a given joint angle or limb position. Examples of tasks involving only static motor control include holding an object still in one or both hands, pushing or pulling against an immovable object, or postural control while standing still. Because this category of tasks requires force regulation without motion, specific proprioceptive feedback mechanisms are used to monitor level and direction of force.

Golgi tendon organs (GTOs) are one of the primary feedback receptors used in force production, because they are sensitive to tension changes in the muscle (Haines, 2002; Baratta et. al., 1995). Once a tension change is sensed, information can be relayed to the muscles about whether to increase or decrease force to reach the target level. GTOs are inhibitory, so they only function at the spinal level to send signals to the muscles to release tension, but still they sense and relay most of the information from muscle output during isometric tasks. Cutaneous receptors also play a large role in feedback and force control mechanisms. Slowly adapting receptors such as Ruffini endings and Pacinian corpuscles are active as long as a stimulus is present which means they respond to pressure or skin distention, especially in the fingertips where the receptive field is smallest and receptor density is highest (Haines, 2002). What this means is that, especially in grasping or pinching tasks, these receptors continually give feedback on how much force is being applied to the object being pinched and whether it is too much or too little. Together with the GTOs, these are only the mechanisms that convey force information to the brain. The nervous system is what actually regulates the force production.

To regulate this muscle force, the nervous system uses one of two mechanisms: recruitment of motor units or firing rate of active motor units (Milner-Brown et al, 1973; Robertson, 1982; Benjuya, 1986). Henneman et al. (1965) described the order in which motor units are recruited, namely that they are recruited in a systematic fashion according to size with the smallest being first. As force increases, there is an increase in motor unit recruitment up to 50-80% of maximum voluntary contraction (MVC) depending on the muscle, after which the only increases in force can be attributed to an increase in firing rate (frequency) of the units already active in the contraction (Milner-Brown et al., 1973; Linnamo et al., 2003). According to Linnamo and colleagues (2003), static motor skills can recruit new units to to achieve higher force levels before having to increase firing rate, compared to dynamic skills. These results could be indicative of the efficiency of underlying mechanisms like the GTO's and deep pressure receptors in feedback sensitivity and delivery. However, static action is not often isolated in activities of daily living. Therefore, an in depth review of dynamic motor control is also in order.

1.2 Dynamic Motor Control

The changing in length of a muscle due to a dynamic contraction alters joint angle as well as limb position of the parts of the skeleton to which the muscle is attached. This movement can be against resistance so that varying amounts of force need to be applied, or it can be free motion with the only resistive force being gravity or the inertial mass of the limb (McGinnis, 2005). In either condition, muscle length changes are sensed by proprioceptors to provide feedback about joint angle and limb position at the onset, during, and after the movement is performed.

The major proprioceptive feedback mechanism during dynamic motion is the muscle spindle (Schmidt, 2005; McGinnis 2005; Haines, 2002; Mugge et al., 2010, Knapik et al., 1983). Muscle spindles lie in parallel to muscle fibers and detect changes in length of the muscle during movement. These, along with joint receptors and cutaneous receptors, provide feedback that relates the position of each limb in reference to the body, to each other, and to the environment in order to move, reach, and attain the intended goal or behavior (Haines, 2002). This feedback loop enables the nervous system to control contractile velocity and movement speed and direction through the same mechanisms used for force control, motor unit recruitment and firing rate.

Motor unit activity during dynamic movement is complex because of the variability built into the movements. In isometric contractions, the muscles are not moving so the only feedback and control necessary is force, but in concentric and eccentric contractions involved muscles (agonists and antagonists) are changing length in different directions and at different rates in order to achieve some common motor skill or task. Recruitment rates follow the same order, but agonist and antagonist muscles fire in various patterns to elicit different movements (Robertson, 1982). Research shows that dynamic movements have lower recruitment thresholds than static movements and require a higher firing rate to operate at the same relative force level for similar durations (Robertson, 1982; Linnamo et al. 2003). These thresholds vary by muscle and contraction type, and are sometimes higher or lower depending on conditions and environment (Benjuya, 1986; Robertson, 1982; Brush, 1966).

Research has also brought attention to limitations in dynamic motor skills. More specifically, Yu et al (2010) recently showed limitations in limits of control of the thumb and fingers during flexion and extension. Subjects showed a deficit in control during single finger extension because of enslavement, where maximal control could not be achieved due to movement and force production that occurred simultaneously in those fingers not being used. Flexion showed a great independence but subjects still were not able to reach maximal flexion levels because of musculotendinous factors as well as neural components. Therefore, overall dynamic motor performance was hindered because of crossovers between neural correlates and the muscular structure of the phalanges.

This research leads into the clinical relevance of this field pointedly. Since the field is well saturated with information about control mechanisms and feedback sources for both force control and free motion, there is now an opportunity to start determining how different types of motor skill are performed by different populations.

1.3 Comparisons and Applications

While the field is fairly expansive and comprehensive in static and dynamic motor skills individually, there is very little research that has compared the two sets of skills and found advantages and/or disadvantages of either for any particular task. Sergio et al. (1998) spent time working with monkeys in isometric force versus limb movement tasks and changes that occurred in the temporal pattern of the primary cortex activity during the tasks. Results showed minimal relation between activity patterns during either task.

Another study, by Murphy and Wilson (1996), showed poor correlations between isometric tests and dynamic performance in humans. This was at least partially due to differing motor unit activation patterns between isometric and dynamic movement. However, the study was poorly controlled and the measures were not consistent across the two tasks.

Of even lesser substance is research investigating the transfer of motion-to-force performance. A 2008 study by Venkadesan and Valero-Cuevas held promising results in motion-to-force transitions with the fingertip in a dynamic tapping task. Performance error was not significantly different between the two modes of task, even at the onset of transition, indicating that moving from a dynamic task to a static task with the same outcome goal was feasible. The most recent pieces of literature, though, are finally starting to address applications for this large sum of knowledge through clinical and real world application.

The next step in this area of this research is determining how to apply it to improve quality of life. Using static and dynamic movements more effectively and efficiently to perform high precision tasks is a new area of research on these topics.

Clinically, powered wheel chair companies are using these modes of motor skill to create better controls for their chairs. TBI patients have demonstrated faster, less variable driving performance when using an isometric joystick compared with a traditional movement joystick (Mahajan et al., 2011; Dicianno et al., 2006; Cooper, et al., 2000).

In the non-clinical population, surgeons have shown improved performance during laparoscopic minimally invasive telesurgical operations when an augmented force-feedback system was implemented in comparison with more traditional motion feedback sources (Mitsuishi, 2007). Mitsuishi's research results suggested that the feedback system used in static conditions yields more accurate performance results, even in a dynamic task. Examination of intelligent steering assistant systems has also shown that drivers who receive steering wheel force-feedback perform better in simulations than drivers with conventional steering wheels (Toffin, 2007).

This short list of research supports the contention that this approach is an important next phase for this field. It is important to continue down this path and seek out technological and physiological advancement as it pertains to force versus position control to improve quality of life. Not only is there a gap in the literature regarding simple comparisons, but also in verifying the few studies that have shown significance in using one system over the other in real-world applications, such as wheelchair joysticks and surgical systems. Eventually this research may lead to advancement in the development of smart phones, car safety features and responsive parts like gas and brake pedals, and better rehabilitative techniques for those who have degraded motor or neurological control. There are even indications that this research can be used in the advancement of prolonged space flight. The alteration of motor control programs due to the presence of microgravity affects not only the biomechanics of the space traveler but also more general psychophysical conditions, induced by the extreme environment. The upper limbs are the primary source of locomotion in space and research on the comparisons of static and dynamic motor skills can facilitate the study of learning new motor activation patterns in the absence of gravity. The results of such experiments can be transferred to clinical populations as well, furthering the importance of research in TBI patients and other CNS disorder populations.

Overall, there is vast expanse of literature concerning various physiological and behavioral aspects of static and dynamic motor control. Each area has developed individually in order to separate the mechanisms driving each of the systems and the feedback sources used to help control and regulate them. Now that science is closer to understanding each of these sources individually it's time to put them together and study the advantages of each system and how to use them more effectively to advance medical, recreational, and vehicular equipment in order to improve quality of life for both healthy and clinical populations.

The intent of this study is to compare performance of a static tracking task and a dynamic tracking task using the index fingers of both hands. The tracking tasks will be performed through isometric flexion force production with the index fingers for the static task and through flexion and extension of the index fingers for the dynamic task. Performance will be assessed as the dependent variable using error scores of test trials after a set of practice trials, one score for accuracy and one score for consistency. The goal is to assess whether a difference in performance exists during fine motor tracking when either static or dynamic controls are used. The hypotheses are that for both the accuracy score and the consistency score no difference will occur between static and dynamic test performance.

Chapter 2: Methods

2.1 Participants

Twenty adult volunteers (ten men and ten women; mean age ± SD, 20.6 ± 1.64) participated in this study. To be eligible for participation in this study, individuals must have been between the ages of 18 and 35 years, been right-handed, and reported no neurological disorders. Right hand dominance was determined by the Edinburgh Handedness Inventory, in which participants needed to score a 60 or better to be determined right-handed. Anyone scoring below 60 on the inventory was excluded from the study. Individuals also had to have no previous experience with the experimental apparatus used in this study in order to be included in the experiment.

2.2 Tasks and procedures

This study contained two testing conditions; a static and a dynamic condition. The static task used the manual force quantification system (MFQS) apparatus to measure forces from the index fingers of the left and right hand simultaneously through two force transducers to measure performance of (Spirduso et al, 2005). The participants' fingers were in contact with the rigidly fixed force transducers through the entire task, so no motion was possible. The participants were asked to increase and decrease the level of force applied to the transducers. A computer monitor provided visual display of the task participants performed, which required them to manipulate the individual fingertip flexion forces of the right and left index fingers. Two cursors appeared on the screen. One was considered the target cursor, and the other one was a cursor manipulated by the participants. The X- and Y-axis values of the manipulated cursor were determined by the left and right index finger forces, respectively. Force increases moved the cursor in the positive direction and force decreases moved the cursor in the negative direction. The participants were seated in a chair facing the computer monitor. The height of the chair and the location of the force transducers were adjustable based on the height and arm-hand geometry of the participants. The orientation of the force transducers was adjusted so that the subjects touched the respective transducer pads while the three unused digits were flexed to the palm in a fist. Immobilization of the force transducer apparatus was achieved by a locking magnet on a metal plate. Therefore, this equipment allowed measurements of independent isometric flexion of each digit without any motion of the participants' hands and arms. This allowed for the static testing condition to be met.

The dynamic testing condition consisted of the same computer screen and cursor manipulation, but the testing apparatus was changed to allow flexion of the index fingers at the first metacarpal joint. The dynamic testing apparatus included a device for each of the hands so that the most comfortable and efficient testing position for each participant could be achieved. The participant wrapped the hand around a vertical grip so that each index finger was placed above the grip and able to flex from the pointed position, or straight out, through 90 degrees of flexion. The index finger was placed in a position detection arm that measured the joint angle change as the finger flexed without causing any resistance to the movement. The grip could be lowered, raised, and moved horizontally to allow for every possible hand size. Therefore, X- and Y-axis positive cursor movement was achieved through flexion of the left and right index fingers respectively, and negative movement was achieved through extension of the index fingers.

A maximal voluntary contraction (MVC) was measured initially using a 20-pound maximum force transducer for the static condition in order to normalize each subject's data. Each participant was asked to apply as much force as possible with both index fingers for 3-4 seconds in order to capture the applied force levels. The MVC was employed to determine the absolute value of the range of force used in this study. Each participant was tested in the range of 0-30% MVC for all static trials. The subsequent practice and test trials were measured using a 10-pound maximum force transducer to allow for more sensitivity during data collection. The participants manipulated the cursor with the objective of continuously matching the moving position of the target cursor up and down a line segment rotated 45 degrees clockwise from straight up for a total time of 20 seconds. The force scaling displayed on the monitor was in %MVC in both dimensions so that the movement along 45-degree diagonal line represented equal force production changes by each digit in terms of their respective %MVC.

An explanation of the procedure, a consent form, and the handedness inventory were provided to participants upon arrival. Consent was obtained, right hand dominance was determined, and then the participant performed the first round of testing. All participants were randomly assigned to determine which condition would be tested first, so that five males and five females were tested with the static condition first and the other five males and five females were tested with the dynamic condition first. If the participant was testing with the static condition then the initial MVC test protocol was performed to establish the target force levels for both practice and test trials. After MVC was determined, the individual performed the task with a maximal target force of 30% MVC. The MVC test protocol was not used to scale the dynamic condition data acquisition, since all participants were tested in the 90 degree range of flexion for each digit.

For each condition, a familiarity period of 20 seconds was used to acquaint the participant with the testing apparatus and how to manipulate the cursor. A blank screen was shown and the participant was asked to move the cursor to each of the four corners of the screen and then to move the cursor however he or she chose for the remainder of the 20 seconds. After the familiarity trial, each participant performed 50 practice trials, each lasting 20 seconds with 20 seconds of rest between each trial to minimize fatigue. Once the practice trials were complete a 2-minute break was given, and then 5 test trials under the same time conditions were performed. A break of 24-48 hours was given between the first and second testing sessions to minimize transfer of learning effects between the two tasks. Data to be analyzed were collected only from the actual test trials.

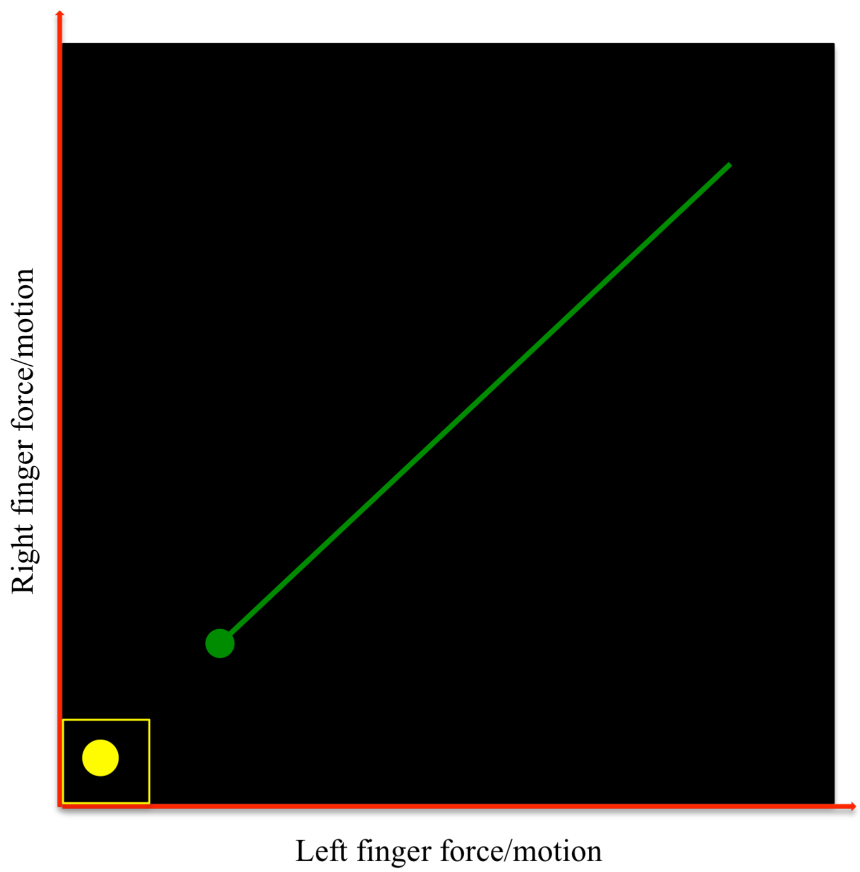

Figure 1: Tracking template design.

The left index finger manipulated the x position of the participant-controlled cursor (the yellow ball, shown in the starting position) and the right index finger manipulated the position in the y direction on the reference frame. The green ball is the target ball, which traveled up and down the diagonal solid line. The position of the cursor reflected the combined force or motion of the two individual fingers.

2.3 Data aquisition

All data were collected in the Motor Behavior Laboratory located in Bellmont Hall on the University of Texas at Austin campus using the MFQS data acquisition system. The MFQS system consisted of a Dell computer, a 14 inch LCD monitor, custom-designed LabVIEW software, a pair of isometric force transducers and a pair of dynamic motion devices with an A/D converter. A LabVIEW software application was used to display the task on the screen as well as to collect and store all data from experiments. Two pairs of strain-gauge sensors were used to measure the individual finger-tip forces in grams. One set (that was calibrated up to 20 lb of force) was used for measuring maximal voluntary contractile force. Another set (that was calibrated up to l0 lb of force) was used to measure the actual performance during static trials for higher precision. The dynamic testing apparatus used a set of potentiometers to measure joint angle changes as flexion and extension occurred. Static and dynamic analog data were sampled at 1000 Hz with LabVIEW.

2.4 Data Analysis

The first process of data analysis compared static data and dynamic data. The target path analyzed was divided into six equal segments along the diagonal line, three each for force increase and force decrease. Two dependent variables were calculated to determine accuracy and consistency of task performance under both conditions during all 6 segments of the task template.

Root mean square error (RMSE) was calculated to assess the average instantaneous accuracy of the tracking performance. RMSE was calculated as the square root of the mean of the squared distance between the cursor and the track ball for each sample.

Consistency of the performance was measured as the coefficient of variation in the magnitude of error (CVE) across all six segments, yielding a measures of smoothness of the tracking performance.

Accuracy and consistency were the performance measures used to investigate any differences that occurred between the static and dynamic motor control conditions. The tracking template was analyzed in six segments to increase understanding of performance at different key stages: take-off, coasting, and approach. The take-off stage occurred at the bottom and top of the template as the participant manipulated the cursor to leave it's starting point and travel along the line as close as possible to the moving target ball. The coasting stage occurred in the middle of the line where the only task was to stay as close to the target ball as possible while not needing to change from force application to force release or from flexion to extension. The approach stage occurred as the participant manipulated the cursor to approach the target at either end of the diagonal line segment either to change direction or to end the task. Figure 2 shows a breakdown of the six segments and their respective placements on the tracking template.

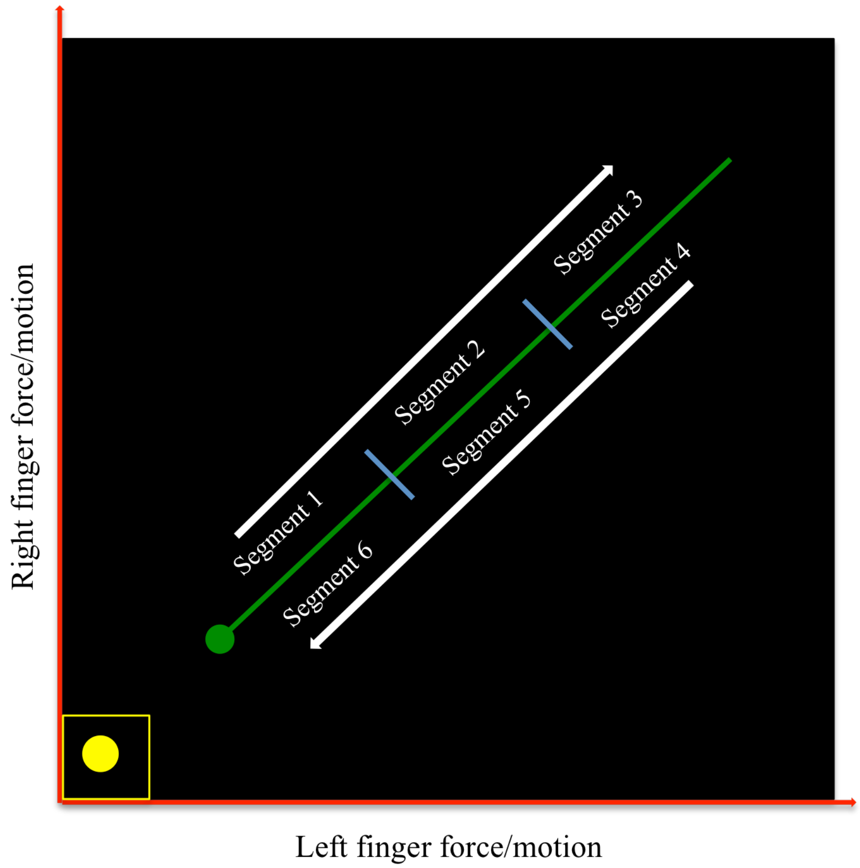

Figure 2: Segments for the tracking template.

Segments 1 and 4 were considered "take off" segments because they were leaving their target, segments 2 and 5 were considered "coasting" segments, and segments 3 and 6 were considered "approach" segments because the cursor was approaching the target. Accomplishment of each segment ideally took 3.33 seconds. Segments were divided this way in order to analyze all 3 phases of the cursor manipulation in both an increasing force/flexion condition and a decreasing force/extension condition.

The data collected from each trial were processed with MATLAB and Excel programs to determine RMSE and CVE for each segment of all five test trials. A coding system was used on all participant records for confidentiality and anonymity regarding the identity and performance of the participants.

Separate statistical analyses were used for testing task performance. For each of the six segments, as well as meaningful sets of segments, an analysis of variance (ANOVA) test with a Latin Square design was performed. The statistical analysis was designed to start with the overall scores and then slowly narrow the focus. For both RMSE and CVE, an overall comparison between static and dynamic conditions was run, collapsing the data across all segments. After that, data was collapsed across segments 1-3 and 4-6 to analyze traveling up the template and then down the template, respectively. Then the segments were grouped into pairs to analyze the take-off, coasting and approaching phases. After that, all six segments were compared individually. The processed data showed one subject with significant outliers so that data was discarded from analysis and the other 19 subjects were used for all ANOVAs. The statistical program R was used for all statistical analysis and the level of significance was set to $p < 0.05$.

Chapter 3: Results

In order to determine if there was a difference between the RMSE in the static condition (across all segments) and the RMSE in the dynamic condition (also across all segments), an ANOVA with a Latin Square design was used. The data were blocked by subject and repetition (labeled as trial) to test the equality of the means. Results showed a condition effect for this accuracy variable, with dynamic RMSE being greater than static RMSE. The results for total RMSE (for each participant and trial across all segments) showed significance with a test statistic of 299.046 distributed as $F(1,166)$ and a p-value less than .001(see table A.1 in Appendices for results table). Figure 3 provides a graphic representation of these results.

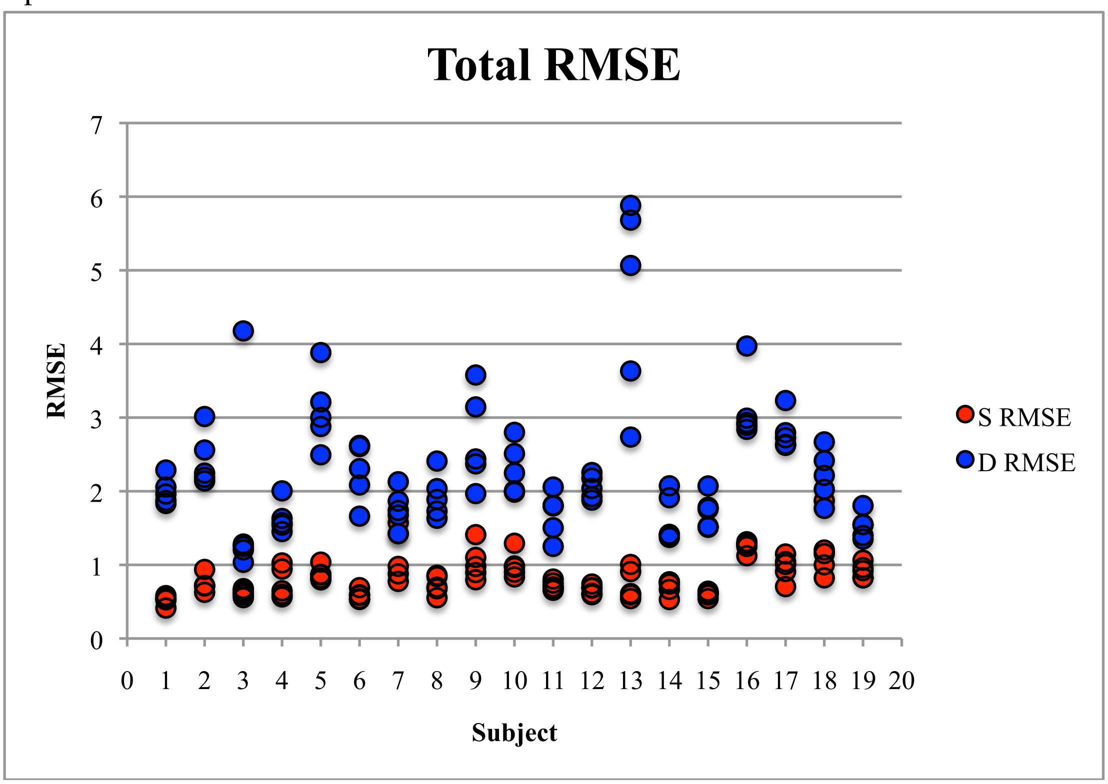

Figure 3: Total static (S) and dynamic (D) RMSE values for each subject for each trial.

In this figure, total RMSE for each subject for each trial is graphed to help visually explain the statistical significance found for condition of task.

To determine any difference between CVE in the static condition and CVE in the dynamic condition, the same ANOVA with a Latin Square design was used. Again, a condition effect was found for this consistency measure, with dynamic CVE being less than static CVE. The results for total CVE for each participant and trial across all segments showed significance of condition with a test statistic of 39.912 distributed as F(1,166) and a p-value less than .001 (see Table A.2 in Appendices for full results).

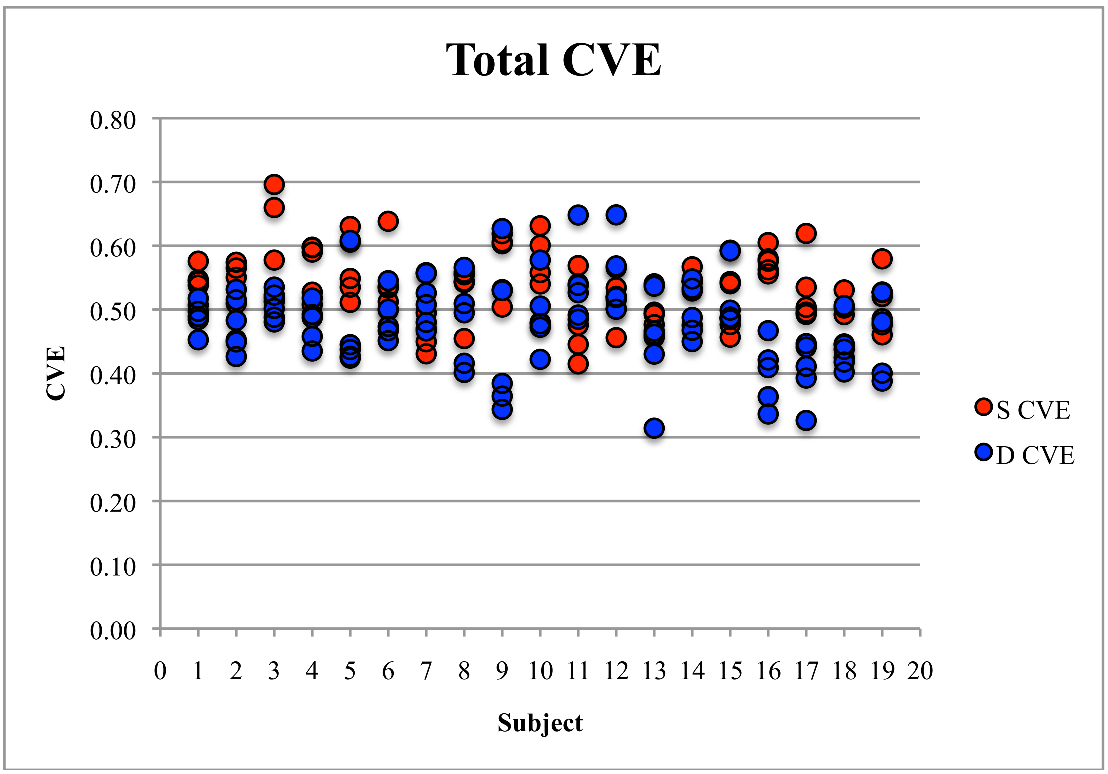

Figure 4: Total static (S) and dynamic (D) CVE values for each subject for each trial.

In this figure, total CVE for each subject for each trial is graphed to help visually explain the statistical significance found for condition of task.

Also something to note was the absence of a repetition effect in both the RMSE and CVE variables, meaning that participants didn't get better as they performed their five test trials in either condition.

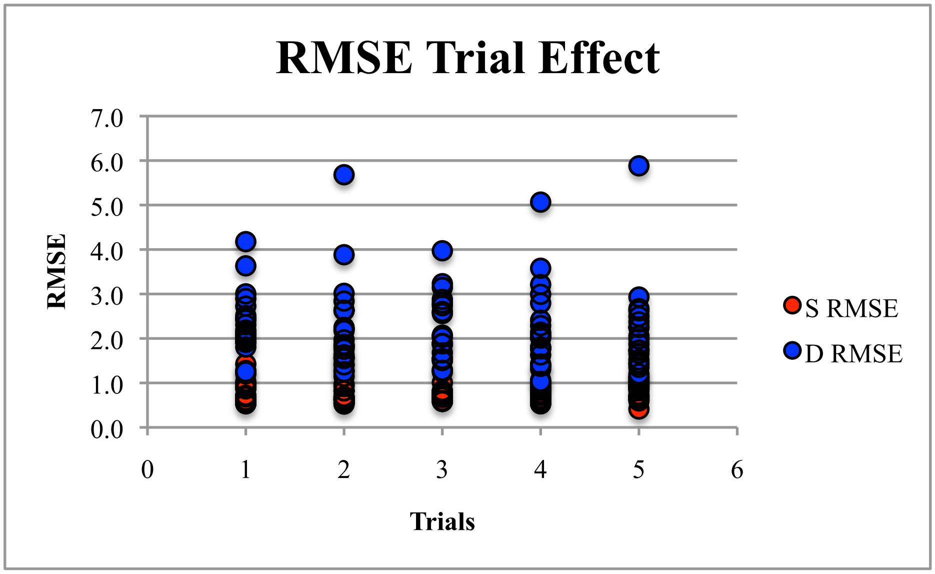

Figure 5: Total static (S) and dynamic (D) RMSE trial effect.

This figure shows the total RMSE values over each trial for each subject, indicating there was no significant change in the values.

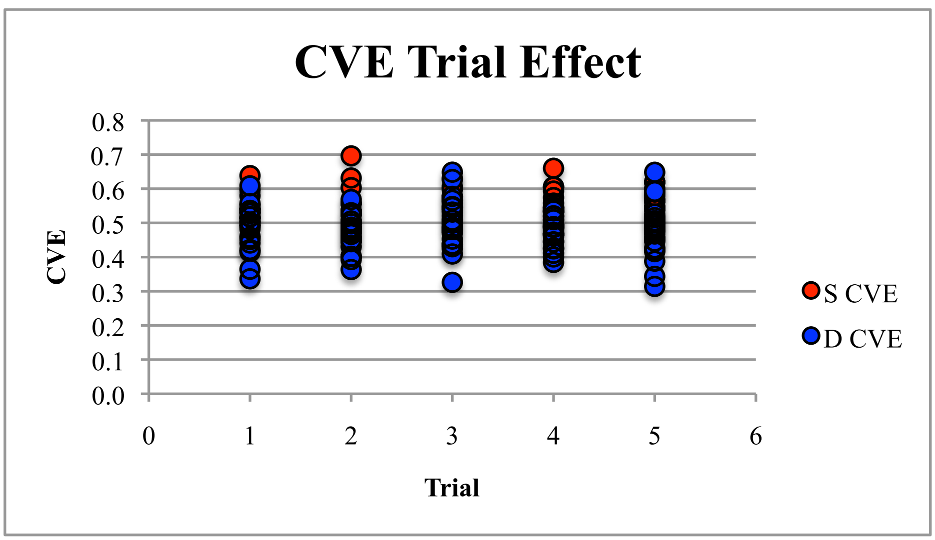

Figure 6: Total static (S) and dynamic (D) CVE trial effect.

This figure shows the total CVE values over each trial for each subject, indicating there was no significant change the values.

Since a significant condition effect was determined at the overall level, meaning static and dynamic performances were, in fact, statistically different for both accuracy and consistency variables, the segments and congruent sets of segments were analyzed as noted in chapter two. Each set and individual segment test showed no trial effect, so performance was not affected by continual learning of the task in any segment. For RMSE, significance of condition was found for each set of segments and each individual segment (see Appendices B-D for tables with test statistics, distributions and p-values). For CVE, each segment and set of segments showed significant difference between the two conditions except for the two take off segments (see Appendices E-G for tables with test statistics, distributions, and p-values).

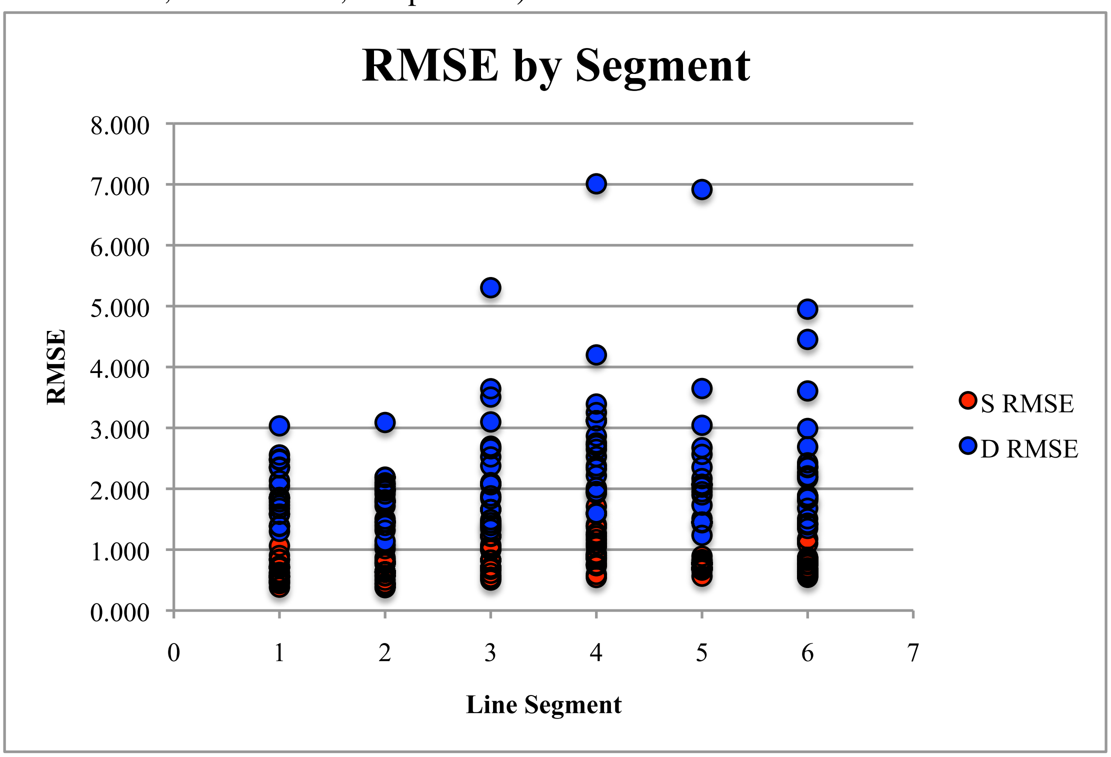

Figure 7: Average static (S) and dynamic (D) RMSE by segment.

This figure shows the RMSE values of each segment for each subject across all trials. For RMSE, a statistical difference was found between conditions for each individual segment as well as all sets of segments.

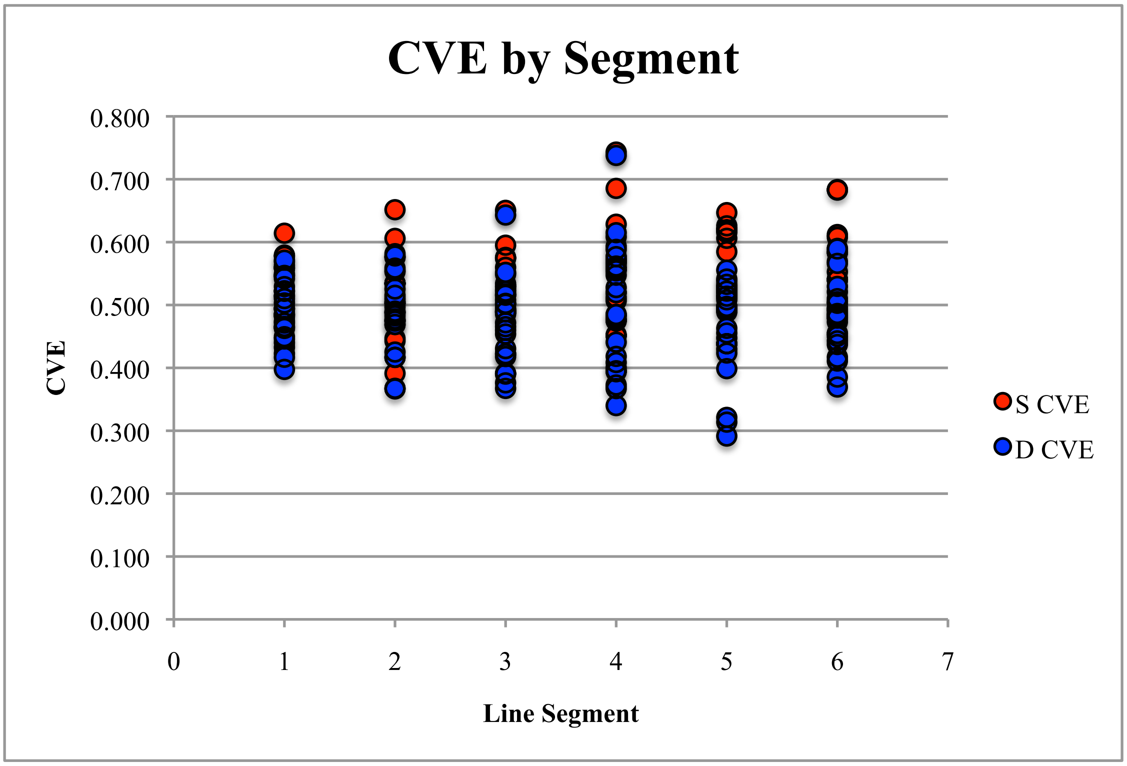

Figure 8: Average static (S) and dynamic (D) CVE by segment.

This figure shows the CVE values of each segment for each subject across all trials. For CVE, a statistical difference was found between conditions for each individual segment as well as all sets of segments except for segments 1 and 4.

The analyses of segments 1 and 4 individually for CVE were the only two tests that did not show significance in the condition effect, always with static CVE being greater than the dynamic CVE condition. Segment 1 was not significant with a test statistic of 1.355 that was distributed as $F(1,166)$ and a p-value of .246. Segment 4 approached statistical significance with a test statistic of 3.875 that was distributed as $F(1,166)$ and a p-value of .0507, which just missed the alpha level set at .05 for significance. There were 24 different tests run (12 each for RMSE and CVE), and 22 showed significance at the condition level.

Chapter 4: Discussion

Finding statistically significant differences in almost every comparison between static and dynamic performance suggests that there could be advantages to using one type of motor action over the other in many fine motor task applications. However, since the differences found did not show better performance for one type of task on both variables, these results require more extensive interpretation.

The RMSE distribution in Figure 3 provides visual evidence of the difference found in accuracy between static and dynamic performance, with static eliciting the lower (better) error score for every subject tested. This finding suggests that with fine motor tasks that require extreme accuracy, isometric control would yield better performance than dynamic control. These findings are in agreement with the studies published by Mahajan et al. (2011), Dicianno et al. (2006), and Cooper, et al. (2000) that showed better driving results with an isometric joystick rather than a position joystick. This study extends those results by controlling for time of task and speed of movement within the task.

Those previous studies also showed less variable (more consistent) driving during their testing in the static mode. While this study determined there was also a significant difference between static and dynamic control in the consistency variable, a closer look was needed to determine if our results agreed with the previous findings.

While the CVE data (see Figure 4) wasn't as different between conditions as the RMSE data (see Figure 3), it was visibly evident that for the majority of subjects the *dynamic* scores were closer to zero and therefore more consistent, than the static scores. While the scores for both methods were much closer together, the scores within each method were also tightly grouped so the variance was small. These findings suggest that for tasks that require large amounts of consistency, dynamic control methods might be better suited. So, in this regard, these results do not support the findings by Mahajan et al. (2011), Dicianno et al. (2006), and Cooper, et al (2000).

In general, these findings suggest that static task performance was more accurate but dynamic task performance was more consistent in the fine motor tasks studied. This could be because minor adjustments, and therefore both higher accuracy and high variability, are more prominent in producing low levels of force than producing almost full range joint motion. Gradually applying or releasing low levels of force without motion can require smaller motor units to be recruited or turned off, which results in small variations in force, while moving the digit through the full range of motion tends to be produced more smoothly, if not as accurately. Therefore, the dynamic condition could show smaller consistency scores due to the nature and sensitivity of the task while still having greater error (distance from the moving target).

This reversal of performance advantage between conditions may be consistent with other studies already published. The finding that the static condition was more accurate and less consistent seems to support the studies done by Mitsuishi et. al., (2007) and Toffin et. al.(2007), where improved surgical performance and improved driving performance (dynamic conditions) were achieved using force-feedback (static condition) methods. The force-feedback methods created the ability to have more accurate results in tasks that already showed consistent results prior to the addition of the feedback system. So in that regard this study’s results, while performed as separate tasks, are consistent with those studies that combine both static and dynamic methods to improve task performance.

This reversal of performance advantage between conditions is also consistent with the suggestion that different underlying sensory feedback mechanisms offer differential support for accuracy and consistency. The pressure and force sensing receptors and sensory pathways active in static task performance may be best suited for quick adjustments, which enhance accuracy but results in many more small corrections, and so a less smooth and consistent motor output. On the other hand, kinesthetic motion sensory mechanisms and pathways are closely tied to voluntary motion production, and so assist in producing smooth, consistent actions in unloaded conditions, though they are less able to make quick, small error corrections and so demonstrate greater error measures.

Because the total results of both variables showed statistically significant differences between the two conditions across all dimensions, it was necessary to determine whether those difference existed at all levels of the task, or if one segment or set of segments was so distinctly different that they overrode the similarities of the other segments. The results of the analyses of segment differences showed significance at almost all levels of the task. Each segment and set of segments were significantly different in accuracy (RMSE) at the $p < .001$ level. For each phase of the task – take off, coasting, and approach – the same difference existed between the conditions. And then within each segment, the difference still existed. These results demonstrated that for accuracy the difference in conditions existed at every level of the task.

However, for the consistency variable (CVE), while most segments showed differences in consistency similar to those shown for the entire task, there were two individual segments that did not show significant differences between conditions. Those two segments, segment 1 and segment 4, were both take off segments. This means that leaving the start point to travel the line upward and changing direction to travel the line downward showed no differences in consistency or smoothness between the static and dynamic conditions.

An interesting thing to note beyond the comparisons of condition is that there was not a trial effect for any of the comparisons (see Figures 5 and 6, the p-values for all trial effects are provided in the Appendices). This lack of trial effects for each analysis indicates that the 50 practice trials before the 5 test trials were enough to create at least a plateau in task learning, a crucial element to the design and interpretation of this study. If learning were still transpiring during the test trials, any statistical difference found might have been due to a learning effect that occurred over the trials, which would be a confounding variable.

Overall, while comparison of these types of tasks is important and necessary, it is also important to realize that most ADL's require a combination of static and dynamic control and better understanding when and if either of those is a better choice of control can yield improved performance in those activities.

Chapter 5: Conclusion

The two conditions of fine motor control were significantly different both at the overall task level and also through most of the individual and paired segments of the task. Visual inspection of the data indicated that the static control condition yielded more accurate performance while the dynamic control condition yielded more consistent (smooth) performance. Consistency data for the two take off segments of the task were not different between the two conditions, though they were for all other segments. The results, overall, indicate that the two different control methods do result in different task performance characteristics. More research, both comparing and combining the control methods, and examining them with different tasks and musculature, is needed to determine more precisely how robust these findings are and where each of the types of task can be most advantageous.

Appendices

Appendix A: Total RMSE and CVE Results

Table A.1: Total RMSE results of an ANOVA with a Latin Square design. Significance is shown with a test statistic of 299.046 distributed as F(1,166) and a p-value less than .001.

Total RMSE					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	34.36	1.91	5.925	7.09e-11***
Trial	4	0.23	0.06	0.179	0.949
Condition	1	96.34	96.34	299.046	< 2e-16***
Residuals	166	53.48	0.32		

Table A.2: Total CVE results of an ANOVA with a Latin Square design. Significance is shown with a test statistic of distributed as F(1,166) and a p-value less than .001.

Total CVE					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	0.1029	0.00572	1.648	0.0538
Trial	4	0.0087	0.00218	0.63	0.642
Condition	1	0.1384	0.1384	39.912	2.35e-09***
Residuals	166	0.5758	0.00347		

*Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

Appendix B: Increasing and Decreasing RMSE Results

Table B.1: Results for RMSE, segments 1-3. Significance is shown with a test statistic of 289.12 distributed as F(1,166) and a p-value less than .001.

RMSE Increasing					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	21.52	1.2	4.316	1.64e-07***
Trial	4	0.82	0.2	0.737	0.568
Condition	1	80.07	80.07	289.12	< 2e-16***
Residuals	166	45.97	0.28		

Table B.2: Results for RMSE, segments 4-6. Significance is shown with a test statistic of 176.126 distributed as F(1,166) and a p-value less than .001.

RMSE Decreasing					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	63.48	3.53	5.443	6.91E-10
Trial	4	1.01	0.25	0.388	0.817
Condition	1	114.11	114.11	176.126	< 2e-16***
Residuals	166	107.55	0.65		

*Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

Appendix C: Task Phase RMSE Results

Table C.1: Results for RMSE, segments 1 and 4. Significance is shown with a test statistic of 279.136 distributed as F(1,166) and a p-value less than .001.

RMSE Take Off					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	29.43	1.63	4.201	2.88e-07***
Trial	4	0.46	0.12	0.298	0.879
Condition	1	108.62	108.62	279.136	< 2e-16***
Residuals	166	64.6	0.39		

Table C.2: Results for RMSE, segments 2 and 5. Significance is shown with a test statistic of 154.616 distributed as F(1,166) and a p-value less than .001

RMSE Coasting					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	34.76	1.93	3.64	4.63e-06***
Trial	4	0.25	0.06	0.116	0.977
Condition	1	82.02	82.02	154.616	< 2e16***
Residuals	166	88.06	0.53		

Table C.3: Results for RMSE, segments 3 and 6. Significance is shown with a test statistic of 227.613 distributed as F(1,166) and a p-value less than .001.

RMSE Approach					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	60.09	3.34	7.649	2.89e-14***
Trial	4	1.06	0.27	0.608	0.658
Condition	1	99.34	99.34	227.613	< 2e-16***
Residuals	166	72.45	0.44		

*Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

Appendix D: Individual Segment RMSE Results

Table D.1: Results for RMSE, segment 1. Significance is shown with a test statistic of 319.987 distributed as F(1,166) and a p-value less than .001.

RMSE Seg 1					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	14.07	0.78	3.053	8.45e-05***
Trial	4	1.39	0.35	1.356	0.251
Condition	1	81.93	81.93	319.987	< 2e-16***
Residuals	166	72.69	0.44		

Table D.2: Results for RMSE, segment 2. Significance is shown with a test statistic of 142.142 distributed as F(1,166) and a p-value less than .001.

RMSE Seg 2					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	11.28	0.63	1.431	0.123
Trial	4	1.88	0.47	1.073	0.372
Condition	1	62.24	62.24	142.142	< 2e-16***
Residuals	166	72.69	0.44		

Table D.3: Results for RMSE, segment 3. Significance is shown with a test statistic of 141.357 distributed as F(1,166) and a p-value less than .001.

RMSE Seg 3					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	67.78	3.77	5.427	7.47e-10***
Trial	4	1.91	0.48	0.688	0.602
Condition	1	98.09	98.09	141.357	< 2e-16***
Residuals	166	115.19	0.69		

Table D.4: Results for RMSE, segment 4. Significance is shown with a test statistic of 128.509 distributed as F(1,166) and a p-value less than .001.

RMSE Seg 4					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	71.95	4	3.694	3.56e-06***
Trial	4	2.62	0.65	0.605	0.66
Condition	1	139.07	139.07	128.509	< 2e-16***
Residuals	166	179.64	1.08		

Table D.5: Results for RMSE, segment 5. Significance is shown with a test statistic of 87.337 distributed as F(1,166) and a p-value less than .001.

RMSE Seg 5					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	81.24	4.51	3.771	2.42e-06***
Trial	4	1.35	0.34	0.281	0.89
Condition	1	104.53	104.53	87.337	< 2e-16***
Residuals	166	198.67	1.2		

Table D.6: Results for RMSE, segment 6. Significance is shown with a test statistic of 105.949 distributed as F(1,166) and a p-value less than .001.

RMSE Seg 6					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	70.1	3.89	4.101	4.72E-07***
Trial	4	1.23	0.31	0.323	0.862
Condition	1	100.61	100.61	105.949	< 2e-16***
Residuals	166	157.63	0.95		

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

Appendix E: Increasing and Decreasing CVE Results

Table E.1: Results for CVE, segments 1-3. Significance is shown with a test statistic of 10.65 distributed as F(1,166) and a p-value of .00134.

CVE Increasing					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	0.1148	0.00638	1.024	0.43598
Trial	4	0.0305	0.00762	1.223	0.30302
Condition	1	0.0664	0.06637	10.65	.00134**
Residuals	166	1.0345	0.00623		

Table E.2: Results for CVE, segments 4-6. Significance is shown with a test statistic of 32.873 distributed as F(1,166) and a p-value less than .001.

CVE Decreasing					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	0.2813	0.01563	2.17	.00569**
Trial	4	0.0135	0.00338	0.469	0.75817
Condition	1	0.2367	0.23673	32.873	4.54e-08***
Residuals	166	1.1955	0.0072		

*Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

Appendix F: Task Phase CVE Results

Table F.1: Results for CVE, segments 1 and 4. Significance is shown with a test statistic of 5.488 distributed as F(1,166) and a p-value of .0203.

CVE Take Off					
	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Subject	18	0.1743	0.00968	1.064	0.3934
Trial	4	0.0188	0.0047	0.516	0.7242
Condition	1	0.05	0.04996	5.488	.0203*
Residuals	166	1.5113	0.0091		

Table F.2: Results for CVE, segments 2 and 5. Significance is shown with a test statistic of 25.159 distributed as F(1,166) and a p-value less than .001.

CVE Coasting					
	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Subject	18	0.172	0.00955	1.399	0.138
Trial	4	0.0485	0.01212	1.775	0.136
Condition	1	0.1719	0.17187	25.159	1.35e-06***
Residuals	166	1.134	0.00683		

Table F.3: Results for CVE, segments 3 and 6. Significance is shown with a test statistic of 26.266 distributed as F(1,166) and a p-value less than .001.

CVE Approach					
	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Subject	18	0.2246	0.01248	1.433	0.122
Trial	4	0.0312	0.00779	0.895	0.468
Condition	1	0.2286	0.22864	26.266	8.2e-07***
Residuals	166	1.445	0.0087		

*Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

Appendix G: Individual Segment CVE Results

Table G.1: Results for CVE, segment 2. No significance is shown with a test statistic of 1.355 distributed as F(1,166) and a p-value of .246.

CVE Seg 1					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	0.1699	0.009437	0.679	0.828
Trial	4	0.0714	0.017854	1.285	0.278
Condition	1	0.0188	0.01882	1.355	0.246
Residuals	166	2.3059	0.013891		

Table G.2: Results for CVE, segment 2. Significance is shown with a test statistic of 4.039 distributed as F(1,166) and a p-value of .0461.

CVE Seg 2					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	0.3451	0.01917	1.432	0.1223
Trial	4	0.0766	0.01915	1.431	0.226
Condition	1	0.0541	0.05406	4.039	.0461*
Residuals	166	2.2218	0.01338		

Table G.3: Results for CVE, segment 3. Significance is shown with a test statistic of 10.357 distributed as F(1,166) and a p-value of .00155.

CVE Seg 3					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	0.2404	0.01336	0.851	0.63801
Trial	4	0.1443	0.03608	2.299	0.06096
Condition	1	0.1625	0.16253	10.357	.00155**
Residuals	166	2.6049	0.01569		

Table G.4: Results for CVE, segment 4. No significance is shown with a test statistic of distributed as F(1,166) and a p-value of .

CVE Seg 4					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	0.661	0.03674	1.438	0.1016
Trial	4	0.062	0.01553	0.627	0.644
Condition	1	0.096	0.09601	3.875	0.0507
Residuals	166	4.112	0.02477		

Table G.5: Results for CVE, segment 5. Significance is shown with a test statistic of 23.998 distributed as F(1,166) and a p-value less than .001.

CVE Seg 5					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	0.549	0.0305	2.056	.00951**
Trial	4	0.0552	0.0138	0.931	0.44751
Condition	1	0.356	0.356	23.998	2.27e-06***
Residuals	166	2.4623	0.0148		

Table G.6: Results for CVE, segment 6. Significance is shown with a test statistic of 18.221 distributed as F(1,166) and a p-value less than .001.

CVE Seg 6					
	Df	**Sum Sq**	**Mean Sq**	**F Value**	**Pr(>F)**
Subject	18	0.4081	0.02267	1.35	0.163
Trial	4	0.0197	0.00492	0.293	0.882
Condition	1	0.306	0.306	18.221	3.3e-05***
Residuals	166	2.7878	0.01679		

*Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

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Vita

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